LOW-PROFILE DYNAMIC WRIST ORTHOSIS DEVICE FOR PEDIATRIC PATIENTS WITH WRIST MOTOR IMPAIRMENT

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Abstract

Pediatric patients with motor impairments often experience muscle imbalances in the wrist flexors and extensors, which causes the hand to be dropped in a biomechanically-unfavorable position for producing grasping forces. An existing device uses an elastic strap to hold up the hand in an attempt to allow for dynamic movement. The previous design was used as a baseline to create a more low-profile and dynamic design for these patients, resulting in thermoplastic, piano wire, and coil spring-based prototypes. Professional response via an Institutional Review Board approved survey indicated that each of these new designs were considered an improvement to the current orthosis devices used in the UVA Occupational Therapy department. The thermoplastic device scored highest overall in this expert opinion survey, including over the previous capstone team's elastic design. Some notable overall successes of the new designs included accomplishing low-profile capability, elevation of the wrist, and palmar sensation. Testing was also performed on the thermoplastic device in order to determine the weight bearing capacity of the prototype, allowing an age limit to be attributed for patients who would potentially use the device.

Keywords: motor impairments, orthotics, pediatric patients, wrist orthosis

Introduction

Children affected by motor impairments caused by cerebral palsy or muscular dystrophy, or acquired through injury such as stroke, can have weak wrist extensor muscles. On average, cerebral palsy affects 1 in every 323 children muscular dystrophy affects 1 in every 7,250 male children in the US every year.[1,2] Strokes affect 12 in every 100,000 children in the US every year.[3] In current therapy practices, occupational therapists (OT) use one of two methods for treating weak wrist extensor muscles; one way is to use a static splint, which assists in biomechanical positioning and allows for optimal joint alignment and controlled movement for the patient.[4] The other way is to use no splint and focus solely on strengthening the wrist extension abilities of the patient. A study compared the effect of static versus dynamic splinting on dexterity, pinch strength, and grip strength between children with and without cerebral palsy. Results indicated that static splinting or no splint at all did not improve any of the tests listed above for the patients. Dynamic splinting was the only form of treatment that improved the tests for the children with cerebral palsy.[5] Based on the results of these studies, a dynamic splint should strengthen the wrist extensor muscles of patients more than a static or no splint method.

There are several current methods used within occupational therapy and physical therapy to work with patients suffering from weak extensor muscles. Primarily, weak wrist extensors in children under 18 years of age are treated with occupational therapy that is tailored to their specific degree of weakness and other surrounding conditions. For example, some patients have much greater mobility and therefore spend only a small portion of their therapy time working on improving wrist and grip strength, while other patients suffer more acutely in this region and need a lot more extensive work just to be able to have some function in their hands.[6] The most common physical device support to occupational therapy is the Benik splint, due to its affordability, ability to be easily tailored to a child's size, comfort, and low profile nature.[6,7] Use of these splints requires a significant amount of effort from the OT and caretaker to manually work on the patient's wrist elevation,

since the Benik splint is static and does not have a dynamic component to assist with that function. Another device often used is the Deroyal wrist splint, which allows for static progressive splinting to increase range of motion. However, this is likely mainly used for adults or older children that do not have other dermal sensitivities as it is very bulky, requires tension setting, and would impede grabbing items as encouraged within therapy. Finally, another device used is the Dinosaur design splint wrist extension device, which allows for dynamic splint placement and wrist motion.[8] This device has been shown to improve wrist strengthening in patients of a wide age range.[9] However, similar to the Deroyal device, this splint is also incredibly obtrusive so is not used in practice for child-centered occupational therapy and it does not allow for the patient to train their grip simultaneously.

In terms of the actual assessments performed during therapy, there are various methods used which are tailored to each patient depending on the developed relationship with the OT and his/her understanding of the patient's ability.[10] There are some benchmarks that relate to a patient's age and bone development, which can range from ability to hold a golf ball-sized item under one pound (1 lb.), to the ability to transfer an item up to 10 pounds from one hand to another.[6] These metrics have complicated processes that are involved in choosing them, which is what each patient's OT is responsible for developing. Additionally, the Jebsen Hand Function Test is a commonly used metric for children aged 3-12 for determining general functionality of the hand.[11]

Previous Capstone Work

Chaillo et al. developed a potential aid for these patients, shown in Figure 1.[12]

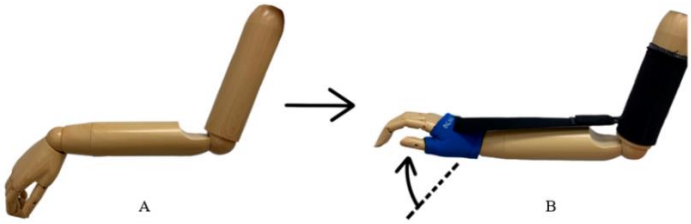

Figure 1: Previous Design for Low-Profile Dynamic Wrist Orthosis. Image A represents a wrist with weak extensor muscles not wearing an orthotic device. Image B represents the same wrist wearing the existing low-profile dynamic wrist orthosis. The bottom arrow on Image B demonstrates the orthosis pulling the wrist up to the 20° neutral position.

The recognized design constraints by the previous team were crucial for the progression of the wrist splint: allowing dynamic movement and variable tension, durable, low-profile, supporting proper wrist and thumb positions, and customizable per patient. While those constraints still remain critical for our adaptations to the design in our own project, the necessity for improvement upon the previous design was determined because of identified shortcomings in the design, materials and process. The strap and attachment point to the upper arm create added height, making the design high-profile to a degree, which is the opposite of the desired design constraint. In addition, the force generation is not isolated to the strap. When the child flexes their wrist, the strap pulls on the elastic of the compression sleeve and the dorsal side of the Benik splint. Intended goals included implementing a different method of force generation and making the design more low-profile. It is important to note that the previous team also created an Institutional Review Board-approved protocol. While the present aims had initially been to carry out a clinical trial following their protocols, not enough patients fitting the criteria were identified by the OT in time to complete the trial.

The primary OT on the study is utilizing a variation of this design, referred to as the "loose elastic design", which also exhibits major shortcomings from the initial design goals. It is hypothesized that the baseline design and loose elastic design both utilize materials which will not achieve the desired elevation of the wrist over time due to permanent deformation at the tension points in the elastic strap of the device. This design's mechanics are represented in the below free body diagram (Figure 2).

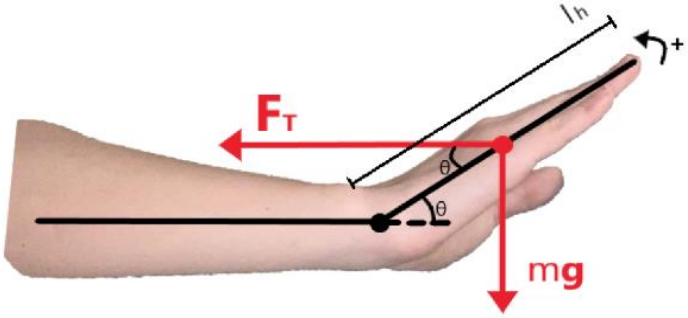

Figure 2: Free Body Diagram of Existing Design. The hand was modeled as a beam with the wrist serving as a hinge and muscle tone was excluded.

Here, the arm is fixed, but the wrist and hand were modeled as a hinge and a beam, respectively. Multiple assumptions followed; the hand is static, the strap contacts the middle of the total hand length, and there is no muscle tone in the forearm. Ignoring general force contributions in the muscle for simplification purposes means that the required force to hold a hand at neutral would not change depending on the degree of muscle tone in various patients. The resulting equations from this model are shown below, where F_T represents the force required in the strap to keep

the hand elevated at θ=20˚ and l_h represents the total hand length.

$$\sum\tau = I\alpha = 0 \quad [1]$$

$$-mg * \left(\frac{l_h}{2}\right) * \cos(20) + F_T * \left(\frac{l_h}{2}\right) * \sin(20) = 0 \quad [2]$$

$$F_T = m * 26.93\ m/s^2 \quad [3]$$

Equation 3 was used to determine if this design's strap could withstand the forces necessary to hold up a hand for the intended patients aged 5-17 years based on the IRB protocol in place. Average body mass for each age group and associated hand masses were calculated.[13,14] The resulting force estimates are found in Table 1.

Age Range (years)	Average Body Mass Males and Females (kg)	Average Hand Mass (kg)	Force Required for Design (N)
4.5-5.5	18.3 ± 2.5	0.1052 ± 0.0144	T_strap = 2.833 ± 0.3878
16.5-17.5	62.2 ± 11.6	0.3577 ± 0.0667	T_strap = 9.633 ± 1.7962

Table 1: Theoretical Required Strap Forces. Tensile forces in the strap needed to hold a hand at a neutral position were estimated using boy masses for males and females in the lower and upper age ranges.

The resulting 2.8 N force falls within the linear regions of the elastic band force-length graphs produced by the previous design.12 The 9.6 N force, however, is in the failure region for the chosen elastic only when a slit is used to fasten the strap to an item on the arm sleeve, such as a button. Even though the forces imposed by a 5 or 17-year-old on an intact strap will not experimentally plastically deform the material, it was noticed that the strap had to be continuously adjusted over time to elevate the hand on a weighted model.

Materials and Methods

Design Ideation

In Table 2, each design represents a different combination from the functional decomposition. There are five different designs that were chosen to compare against the baseline design:

Criteria	Weight	Baseline	Loose Elastic	Coil Spring	Tension Spring	Semi-rigid	Rods
raises wrist to 20* neutral	3	0	-1	0	0	0	0
protect skin (no rubbing)	2	0	0	-1	-1	0	0
low profile	2	0	-1	1	0	1	1
sensation	1	0	0	0	0	0	0
support the thumb in abducted position	2	0	0	0	0	0	0
preserves a degree of natural movement	3	0	0	0	0	0	-1
Total		0	-5	0	-2	2	-1

Table 2: Pugh Chart Analysis of Functional Decomposition Designs. Each criterion listed was given a specific weight from 1 to 3 based on how important the criteria is to the design. Through theoretically assembling each criterion, each criterion was given a score of -1, 0, or 1 for the five designs. A score of 0 means that the device meets the device criteria the same way the baseline does. A score of 1 means that the device does a better job than the baseline. A score of -1 means that the device does not meet the design criteria at the same level as the baseline.

a) Loose Elastic - design currently in use by OT that incorporates a loose elastic arm bandage and a neoprene strap fastened to a Benik splint.
b) Coil Spring - separate hand and wrist rigid straps with a coil spring centered at the wrist joint fastened at either end to the straps, located on the ulnar side of the hand.
c) Tension Spring - separate hand and wrist rigid straps with a tension spring fastened at either end to the straps, located on the dorsal side of the hand.
d) Semi-rigid - thermoplastic (or other semi-rigid) material that extends from base phalanges joints past the wrist on the dorsal side of the hand, with a strap fastened around the palm.
e) Rods - mostly rigid structure, such as piano wire, fastened within a compression sleeve that stretches from the hand past the wrist.
The three designs with the highest scores were chosen for the prototyping stage: semi-rigid, coil spring, and rods.

Semi-Rigid/Thermoplastic Prototyping

In efforts to incorporate materials similar to those in the field of orthotics, the semi-rigid design was accomplished using thermoplastics. High temperature plastics were readily available and required the creation of molds representing an arm and an elevated hand. The first prototype, shown in Figure 4A, was created by shaping high-impact polystyrene (HIPS) over an approximate arm model with a vacuum-forming machine (Formech 300XQ), which was the method used for all following prototype versions. This model was created with a PVC pipe and wood held together by epoxy (Figure 3A). The resulting plastic form was rigid along the wrist and non-supportive against the hand so the transition from the curved arm surface to the straight surface along the back of the hand

needed to be smoother. To mimic basic anatomy more closely, the second arm mold, created with CAD software (Autodesk Fusion 360) was shaped by a CNC milling machine (Roland MDX-40A). Iteration B's forearm ridge, which restricted bending, was altered along with general scaling in Fusion 360 to produce Mold C. A matching 3D-printed nylon model was also generated (Figure 3C). Neoprene and Velcro straps were added to Iteration C (Figure 4C) and the plastic was lined with compressive fabric for skin comfort.

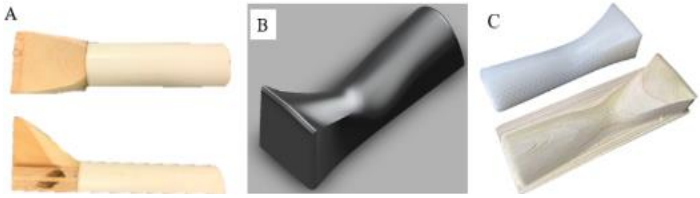

Figure 3A-C: Arm Models for Thermoplastic Mold. Figure A shows the first basic arm model, constructed of PVC and wood, which was used to produce the first thermoplastic design. Figure B demonstrates one iteration of the 3D CAD model used for printing. Figure C shows physical models used for vacuum-forming plastic. The nylon model (top) was created by a 3D printer, and the wood model (bottom) was produced by a CNC mill.

Iteration C exhibited inconsistent and warped bending patterns due to the rounded and continuous upward-curve of the profile. Iteration D, produced with a thicker red HIPS and the same mold, did not fare better; the red plastic required much more force to bend and underwent visible plastic deformation within the test movements. To achieve plastic bending parallel to the joint motion, the wooden model was sanded down to flatten the curve along the wrist. Iterations E and F were produced from the modified mold, but the red plastic of E still required a high downward force. Fabric and straps were also added to the final version (Figure 4F, Figure 5).

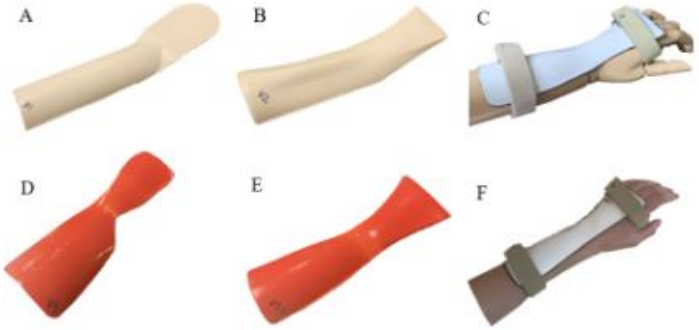

Figure 4A-F: Six Iterations of the Thermoplastic Design. These six designs each have small differences in their overall structure, leading to final design, version 5.2. Primary differences concern the curvature along the arm and the bend at the wrist.

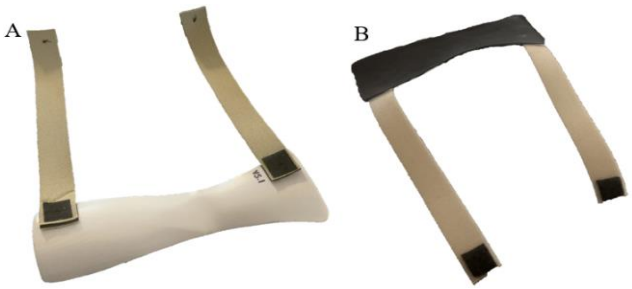

Figure 5A and 5B: Final Prototype of the Thermoplastic Design. Top/Outside (A) of the design shows the thermoplastic with the attachment sites for the straps. Bottom/Inside (B) of the design shows the soft fabric used to protect the skin from rubbing.

Rods/Piano Wire Prototyping

The rod design was implemented through the use of piano wires. The previous capstone team incorporated piano wires into their first few prototype iterations which led to some initial success. To further investigate the success of piano wires, their inclusion into the prototyping stages was vital. The first iteration of the piano wire design was created by cutting a Futuro wrist splint at the bend of the wrist. Five pieces of piano wire were cut into five-inch long sections and bent to 20° angles to meet the design constraint of raising the wrist to neutral. Each wire was wrapped with heat-shrink tubing and sewn into the top and bottom portions of the Futuro wrist splints. The wires rotated in place, and thus the elevation angle no longer held and an additional step was needed to secure them. Hot glue was attached to the top and bottom portions of the wrist splint in the same locations of the wires to ensure further stabilization (Figure 6). During observation of device function, the hot glue began to break down and no longer held the wires in place as intended. With the destabilization of the wires on the wrist splint, the device was no longer serving its original purpose, therefore it failed before further testing could be completed.

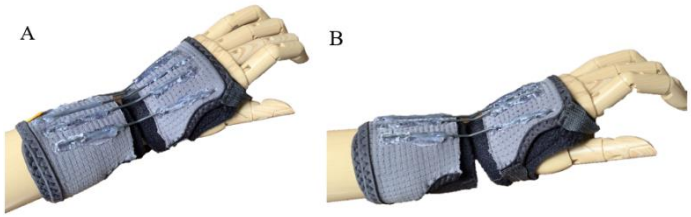

Figure 6A and 6B: Piano Wire Design. The angled top view (A) shows the layout of the piano wires on top of the wrist brace. The side view (B) illustrates 20˚ angle of elevation maintained by the piano wires.

Coil Spring Prototyping

Coil springs return to their original form after undergoing bending forces and would prove useful for the orthosis function. A drugstore wrist splint (Futuro) was chosen for sewing the coil spring mechanism onto. The Futuro splint was cut in half to expose the wrist joint and allow for bending. This way, the spring could function in elevating the hand while attached to the ulnar side of the wrist, as shown in our original design in Figure 7.

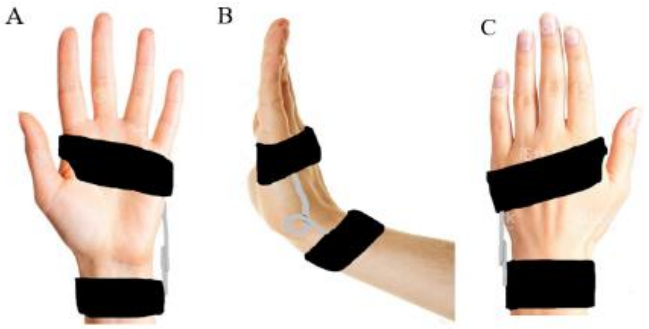

Figure 7A-C: Coil Spring Device Design. The bottom view (A) represents the layout of the straps along the palm of the hand and inside portion of the wrist. The side view (B) demonstrates how the coil will lay on the side of the hand. The top view (C) shows the layout of the straps along the top of the hand and wrist.

To fasten the coil spring to the splint, the brazing technique was to be used for securing each long end of the spring onto pieces of low carbon steel already drilled with six holes each. Finally, the holes would be used to sew the spring into each separated side of the splint. In the first iteration, the following tasks were accomplished: cutting the steel, drilling the holes and smoothing them for sewing purposes, and brazing the coil. However, following the brazing step, when a slight force was applied to the spring one of the ends broke off. This was likely due to over application of heat on that side of the coil, causing the iron to become incredibly brittle. Figure 8 shows the brazed coil prior to its failure. Therefore, the device could not be completed and used for further testing or adaptations.

Figure 8: Brazed Coil Spring. The coil spring is brazed onto a small rectangular piece of steel as a test. Attempts to recreate the joint with specific pieces failed.

Mechanical Testing and Surveys

In order to test the completed thermoplastic device, a makeshift force experiment was constructed. A box of spaghetti, totaling 454 g, was divided into eighths to create known increments of mass. The portion of the thermoplastic device below the wrist was secured to a countertop, leaving the wrist and hand portions of the device exposed. A camera was set to take photographs of each increment of mass that was secured to the middle of the hand portion of the device, thus capturing the angle of elevation at each point of increasing mass. When the device failed at the sixth increment of mass, that 'eighth' was divided in half, and then in half again until the narrowest window of failure was identified. ImageJ software was used to identify the angle at each point and the results were compiled into a graph.

Two surveys were constructed to supplement the mechanical testing with qualitative analysis: a user survey and an expert survey. The user survey was created for the purpose of re-evaluating the initial Pugh chart theoretical analysis with actual experimental results. The survey had four non-impaired user participants which were first given the previous capstone team's design to assess as the baseline. They then received the final thermoplastic device and the nearly-completed piano wire device to assess and score. For the expert survey, shown in Supplement 1, a group of OTs were asked to rank the importance of the Pugh chart criteria given their own professional opinion. Using a virtual device guide, shown in Supplement 2, to learn about our designs as well as the previous team's design, they were to rank all designs using a baseline of whatever current preferred devices used in their practice. The averages of the scores for both surveys were measured and analyzed.

Results

Mechanical Testing

Images from the tests are shown in Figure 9 below.

Figure 9A-C: Samples of images from thermoplastic device testing. These figures, along with many others, were put into ImageJ where the angle was calculated and recorded for later inclusion in a force graph. Figure A shows the initial position. Figure B shows the last measurement before device failure, while Figure C shows the first point of failure.

The results of the thermoplastic mechanical testing are presented below in Figure 10. The failure region, highlighted in blue, lies somewhere between 297.9 g and 312.1 g, where the graph crosses over the horizontal orange line that indicates the initial upright position of the device at 17.979°. Once the device rotates more than the initial

upright angle value, the device is no longer elevating the applied weight and therefore, the device has failed. This failure region indicates that the device is successful for a child up to age 14, based on the national average mass for males and females combined.[13,14]

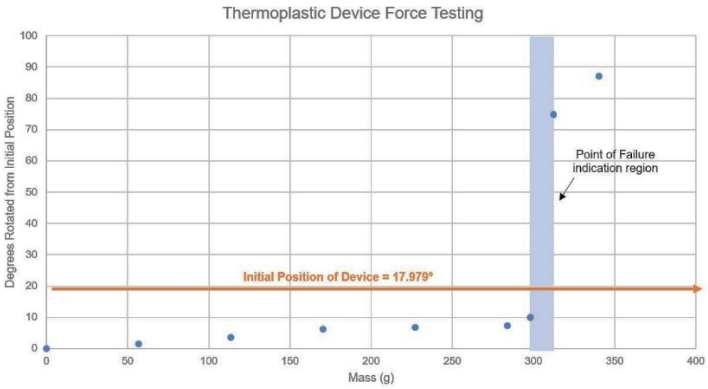

Figure 10: Force Testing of Thermoplastic Design. The horizontal orange line indicates the original position of the device. The light blue area indicates the region where the point of device failure falls.

User Survey

The experimental device design rankings using the original criterion weights from the theoretical analysis are shown below in Table 3. Both of the thermoplastic and piano wire devices scored positively, indicating that the devices were overall an improvement upon the previous team's design according to these users. The devices were also scored equally, indicating that from the user perspective, neither of the devices performed better than the other.

Criteria	Weight	Baseline	Thermoplastic Design	Piano Wire Design
raises wrist to 20° neutral	3	0	1	1
protect skin (no rubbing)	2	0	0.5	0.5
low profile	2	0	1	0.75
sensation	1	0	1	-0.5
support the thumb in abducted position	2	0	-1	0
preserves a degree of natural movement	3	0	0	0
TOTAL		0	5	5

Table 3: Follow-up Pugh Chart Analysis. Conducted with n=4 survey participants using actual devices to analyze. Results are consistent with the initial theoretical Pugh chart in that the semi-rigid (thermoplastic) and rods (piano wire) devices perform better than the loose elastic design. The coil spring was not able to be included in this survey as the prototype was never completed.

Expert Survey

Average criterion weights and device design rankings are shown below in Table 4. Though none of the criteria were deemed unimportant or irrelevant by the occupational therapists, the highest-weighted were raising the wrist to 20° neutral and protecting the patient's skin. With respect to the previous elastic strap design and baseline products, all three of the present designs were believed to provide more palmar sensation, but failed to improve in supporting the thumb out in an abducted position. All four design totals were positive, and most importantly, the thermoplastic was ranked higher than the elastic strap design.

Criteria	Weight	Baseline	Thermoplastic Design	Piano Wire Design	Coil Spring Design	Elastic Strap Design
raises wrist to 20° neutral	3	0	0.67	0	0	0.67
protect skin (no rubbing)	3	0	0	0	0.33	0
low profile	2.25	0	0.67	-0.67	1	-0.33
sensation	2.25	0	0.67	0.33	0.67	0
support the thumb in abducted position	2.75	0	-0.67	-0.33	-1	0
preserves a degree of natural movement	2.75	0	0.67	1	0.33	1
TOTAL		0	5.03	1.08	2.91	4.02

Table 4: Summary of Findings from OT Survey. A total of n=3 OTs participated in this IRB-approved survey. Based on the results of the survey, a new weighting system was calculated from the averages of the OT participant's rankings of each criterion. The subsequent designs were ranked and summated using the averages of their rankings. Results indicate all device ideas performing better than the currently used devices, with the highest score towards the thermoplastic device design.

Discussion

The most notable physical differences between the past and thermoplastic designs are improvements in low profile capacity and palmar sensation, a view also mirrored by surveyed OTs. All present prototype designs removed the need for a strap that adds height and limits the functionality under certain clothing. Additionally, the previous design incorporated a Benik hand splint, which covers the palm and limits the feedback provided by the sensation of and grip on held objects. Subjects of the previous team's approved clinical trial protocol were to be between the ages of 5 and 17 years old. Therefore, one quantitative goal was to create an orthosis that would withstand the weight of a 17-year-old's hand. Experimentally, the thermoplastic device could only hold the weight for a 14-year-old. It is notable that for the mass of female children alone, the device is successful through age 17, which was our initial goal. It is also worth noting that while the national average mass of a male child begins to drastically increase at age 15, this increase may not be as present in male patients affected with motor impairment conditions.[13,14]

The qualitative perspective received from professionals demonstrated that they believe there is a need in the field for an improved product. Positive total scores

across previous and current designs indicate that all work had approached that ideal using various methods. The main objective of the current work was to improve on previous work. Although some of that work was cut short, the thermoplastic prototype scored higher than the elastic strap prototype, which meant that the initial goal was accomplished.

A clinical trial was set up by the previous year's capstone team for completion this year but due to lack of eligible participants, no data was received.[12] The clinical trial data may have been critical in informing the prototyping of this year. The academic shutdown in the middle of the semester prevented access to resources and limited the amount of time available for prototyping. During the initial prototyping stages, there were a few setbacks. With the failure of the hot glue from the first piano wire iteration, a second iteration was to be created with similar initial attachments. Instead of finalizing the piano wire attachments with hot glue, a caulking method was intended. The failure of the initial coil spring mechanism prevented further building of the first iteration. For the user surveys, there were not any patients with motor impairments available to test the devices. Therefore, the user responses are subjective to users who have full mobility of their wrist extensor muscles. For the OT surveys, the OTs were shown the devices virtually rather than in person, as originally intended. Having the prototypes viewed through a virtual forum prevented the OTs from physically handling them, making it less likely that they understood how they truly worked.

In the future, given all prototypes could be completed, clinical trials should be carried out to further assess the potential of each design. Patients with motor impairments providing user feedback on the designs will provide critical information about the likelihood of individuals to wear them and if the device appears to be sufficient for them. Combining feedback from the clinical trials as well as more occupational therapist surveys may lead to a single and improved design. Currently, the semi-rigid design was the most successful. Assuming this success continued throughout clinical trials, some changes should be made before implementation into a clinical setting. The resulting orthosis is intended to be a supplement for occupational therapy. Due to the specificity of the devices for patients, they could not be mass manufactured and sold as a product. Occupational therapists have the expertise required to manufacture the devices, therefore they should be the ones creating them. Before implementing the semi-rigid design into the occupational therapy department, there should be a change in material from high temperature thermoplastic to low temperature thermoplastic. Low temperature thermoplastic allows for easier manufacturing and molding to each patient.

End Matter

Author Contributions and Notes

K.E.H., S.A.M., M.R.Y. designed research, performed research, analyzed data and wrote the paper. W.H.H supervised and edited the technical portion of research.

The authors declare no conflict of interest.

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SUPPLEMENT 1

OCCUPATIONAL THERAPIST SURVEY OF LOW-PROFILE DYNAMIC WRIST/HAND ORTHOSIS PEDIATRIC DEVICES

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QUESTION 1

Rank the following criteria for wrist/hand orthosis devices used for pediatric patients affected with weak wrist extensor muscles.

Place an "X" in the column which corresponds to your ranking for each criterion.

Criteria	**Unimportant/ Irrelevant**	**Helpful/ Relevant**	**Reasonably Important**	**Critically Important**
raises wrist to 20* neutral position				
protects skin (no rubbing/abrasive material)				
low profile (doesn't draw attention, fits with most kinds of clothing)				
sensation in the palm (user can feel item being gripped)				
support the thumb in abducted position				
preserves a degree of natural movement				

QUESTION 2

Rate how you believe **Device 1** does/would compare to the device(s) you currently use in each of the following criteria. Place an "X" in the column which corresponds to your rating.

Criteria	**Worse than your current device(s)**	**The same as your current device(s)**	**Better than your current device(s)**
raises wrist to 20* neutral position			
protects skin (no rubbing/abrasive material)			
low profile (doesn't draw attention, fits with most kinds of clothing)			
sensation in the palm (user can feel item being gripped)			
support the thumb in abducted position			
preserves a degree of natural movement			

QUESTION 3

Rate how you believe **Device 2** does/would compare to the device(s) you currently use in each of the following criteria. Place an "X" in the column which corresponds to your rating.

Criteria	**Worse than your current device(s)**	**The same as your current device(s)**	**Better than your current device(s)**
raises wrist to 20* neutral position			
protects skin (no rubbing/abrasive material)			
low profile (doesn't draw attention, fits with most kinds of clothing)			
sensation in the palm (user can feel item being gripped)			

support the thumb in abducted position			
preserves a degree of natural movement			

QUESTION 4

Rate how you believe **Device 3** does/would compare to the device(s) you currently use in each of the following criteria. Place an "X" in the column which corresponds to your rating.

Criteria	**Worse than your current device(s)**	**The same as your current device(s)**	**Better than your current device(s)**
raises wrist to 20* neutral position			
protects skin (no rubbing/abrasive material)			
low profile (doesn't draw attention, fits with most kinds of clothing)			
sensation in the palm (user can feel item being gripped)			
support the thumb in abducted position			
preserves a degree of natural movement			

QUESTION 5

Rate how you believe **Device 4** does/would compare to the device(s) you currently use in each of the following criteria. Place an "X" in the column which corresponds to your rating.

Criteria	**Worse than your current device(s)**	**The same as your current device(s)**	**Better than your current device(s)**
raises wrist to 20* neutral position			
protects skin (no rubbing/abrasive material)			

low profile (doesn't draw attention, fits with most kinds of clothing)			
sensation in the palm (user can feel item being gripped)			
support the thumb in abducted position			
preserves a degree of natural movement			

QUESTION 6

Which device(s) (if any) would you potentially use with your patients and why? (CIRCLE ALL THAT APPLY; write explanations accordingly).

Device 1 Device 2 Device 3 Device 4

SUPPLEMENT 2

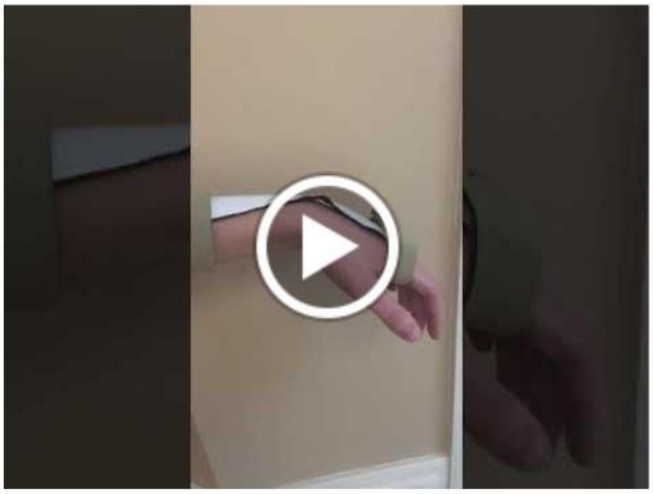
Device Guide for Survey

Capstone Wrist Orthosis Team

Due to the coronavirus and widespread shutdown, we were unable to complete devices 2 and 3 to the best of our hopes. Because of this, we will be attaching photos for device 2 and designs for device 3 with detailed descriptions of how they should work. Device 4 is simply the design the previous capstone team produced, and a modification of this is already used in your department by Sue Berres.

Device 1 - Thermoplastic Design

- Ideally would use low temperature thermoplastics to mold perfectly to each patient's arm, with easy-to-attach adjustable straps to grow with the child
- Soft fabric on the inside for optimal comfort
- Optimally chosen thickness of plastic so it doesn't permanently deform with each movement, but it is strong enough to hold the hand up without any muscular interference
- Can easily go over long sleeve shirts, or under sweaters/jackets



Device 1 - Thermoplastic Design - CONTINUED

Device 2 - Piano Wire Design

- Ideally would use a silicone adhesive to keep the wires in place (right now, we were limited to using hot glue, so while the device used to work, the adhesive properties of hot glue fade over time, and the wires now rotate in their hot glue membranes)
- The wires bent at that angle, encased in silicone tubing for safety to the patient, allow the hand to bend and straighten with enough resistance to hold the hand up without any muscular interference
- The brace is a simple hand brace cut in half
- Can easily go over long sleeve shirts, or under sweaters/jackets

Device 2 - Piano Wire Design - CONTINUED

Device 3 - Coil Spring Design

- This device creation would need to be outsourced to a professional manufacturer, as the brazing process for the metal requires a high level of skill
- The coil gives the resistance necessary to hold the hand up without any muscular interference, while also giving the wrist the flexibility to bend
- The brace is a simple hand brace cut in half
- Can easily go over long sleeve shirts, or under sweaters/jackets

Device 3 - Coil Spring Design - CONTINUED

Device 4 - Elastic Strap Design

- This device was designed by the previous capstone team, and our goal was to improve upon this device
- Some aspects we feel we have improved are:
  - Mobility adaptation: with this device, there are several rotated positions which the strap no longer holds the hand up in the neutral position. Our devices do not allow for that counterproductive rotation
  - Longevity: elastic straps and elastic arm bands have a much greater propensity to deform/stretch over time, rendering the device not as useful as at first. Our devices use materials which do not deform nearly as quickly
  - Low-profile wearability: the outlying strap and tight arm band aspects of this design make it difficult or impossible to be worn with long sleeve clothing, or jackets, and also make it very noticeable. Our devices give the patients much more flexibility with their apparel, as well as encourage patients to wear the device more often because it does not draw as much attention

Device 4 - Elastic Strap Design - CONTINUED